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THE NEED AND IMPETUS TOWARD MORE NON-INTRUSIVE MEASUREMENTS IN INDIAN WIND TUNNELS

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ABSTRACT

Over the last decade non-intrusive measurements have established themselves as the preferred tools of choice for higher productivity in wind tunnels worldwide. At NAL, significant progress has been made in the development and application of these tools for pressure, velocity and density measurements and is currently state-of-the-art worldwide. However, the deployment of these for routine use in high-speed wind tunnels has lagged behind. This paper makes a case for such routine usage as the returns from usage of such techniques in the understanding of flow physics makes the effort worthwhile.

1. Introduction

Wind tunnel measurements play a crucial role in design and improvement of aerospace vehicles. Steady and unsteady surface pressure, load measurements and qualitative visualization form the bulk of wind tunnel data. Over the last two decades, technological advances in lasers, video techniques, optoelectronics, computers and evaluation algorithms allow to extract quantitative information from images of flows. Worldwide, the advances of such image based measurement techniques and decreasing costs of equipment have enabled many research groups to exploit these techniques for extraction of two-dimensional or even three-dimensional data mainly for fundamental research. All data is acquired non-intrusively so that no interference of the flow field by the measurement is to occur. In consequence, the methods developed are particularly suited for the aero-dynamical and aero-acoustical analysis of complex, unsteady three-dimensional flow fields. The acquired data sets constitute a reliable basis for the validation of numerical codes.

In the past decade, many image based measurement techniques have found interest and are even used as a matter of routine in industrial applications[1]. This explains why research establishments like the German Aerospace Center (DLR) and the French Aerospace Agency (ONERA) have developed optical and acoustical field measurement techniques for the acquisition of fluid-mechanical and aero-acoustical quantities and to apply them mainly in large industrial wind tunnels for aerodynamics.

While the development of such techniques in India has kept pace with the advances worldwide, their deployment for routine use has inexplicably lagged behind. This paper will examine a few of the most well established techniques for pressure, velocity and density measurements along with typical case studies carried out at NAL. Published results from the routine application of such techniques elsewhere will be compared to show the potential of such techniques when applied to wind tunnels in India.

2. Flow Diagnostics for Aerodynamics

a. Pressure Sensitive Paints

To measure the surface pressure distribution on any wind tunnel model, conventional pressure measurement systems which are time consuming and limited in spatial resolution are being used. An alternative to this measurement is the pressure sensitive paint (PSP) technique which is based on the principle of oxygen quenching of luminescence [2]. PSP offers higher spatial resolution compared to the conventional electronic sensor based pressure measurement systems

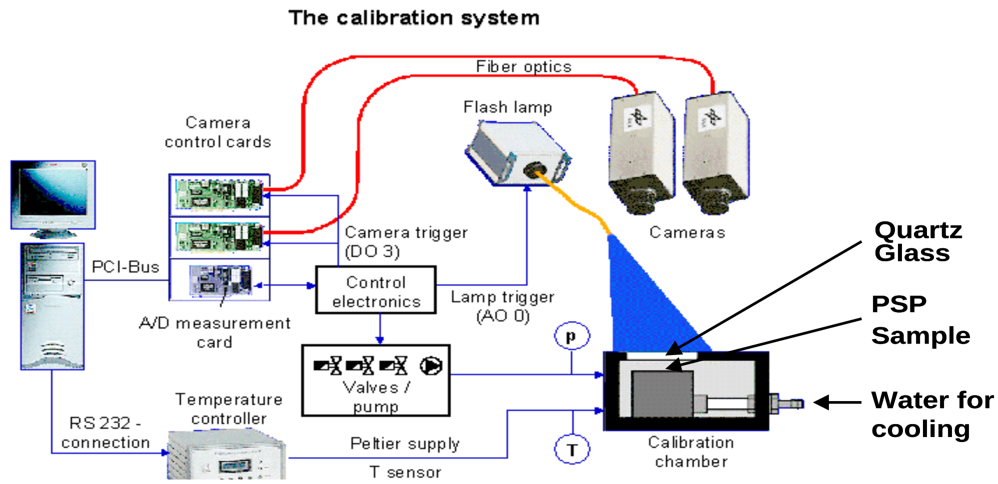

Fig.1 Schematic of NAL PSP system

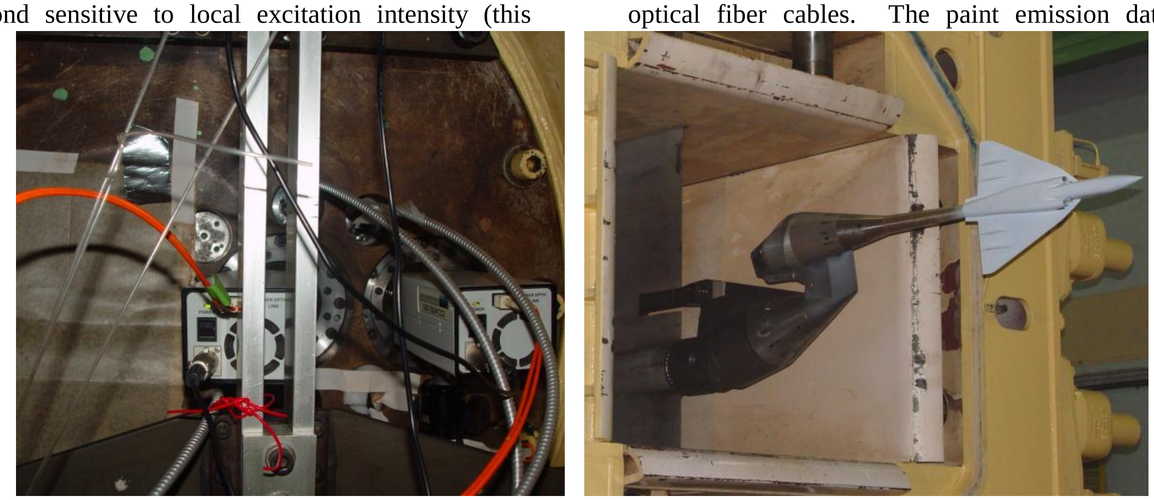

Fig. 1b PSP setup and painted model in the 1.2m tunnel

The pressure sensitive paint developed at NAL is a binary paint based on Pyrene; with one component (blue) sensitive to the changes in pressure and the second sensitive to local excitation intensity (this reference or red component is insensitive to pressure and accounts for the spatial variation in as well as instabilities in excitation intensity and additionally those arising out of model movements relative to the light source). The paint layer consists of a screen layer and an active layer with a total thickness of about 40µm prepared using conventional spray painting techniques both on the cleaned metallic models as well as calibration surfaces.

The intensity based PSP system at NAL consists of an UV-flash lamp, two scientific grade CCD cameras, the calibration equipment and an in-house developed resection based image processing software (Fig 1a). Excitation of the PSP on the model is provided by a xenon flash lamp emitting UV light in the range of about 350 nm wavelength. Optimum distribution of illumination on the entire model surface is obtained by using four illuminator heads connected to the lamp system by four 15 m long optical fiber cables. The paint emission data is acquired by two air-cooled scientific grade 12-bit CCD slow scan cameras with resolution of 1280 x 1024 pixels. The image acquisition is made by a PC based data acquisition system based on two separate PCI-cards. The camera and illumination are triggered and controlled by LabVIEW based software. The image integration time is typically 9-12 seconds so as to have a large pixel fill ratio in the CCD array (to have large signal to noise ratio). The sequence of measurement involves acquisition of images from the two cameras (the pressure sensitive and the intensity sensitive): a) ambient pressure and temperature b) dark images c) pre-run wind-off images d) wind-on images and e) post-run wind-off images. Camera objectives of 8 mm and 12 mm focal length are ideally suited for imaging models in NAL tunnels providing maximum spatial resolution of PSP images. Fig. 1a shows the schematic of the PSP system in calibration and Fig 1b the setup in the tunnel for measurements on a wing body configuration.

By leveraging the capabilities of current desktop workstations, the PSP data can be presented on the same grid as used for CFD as seen in Fig 1c.

PSP is now a routine measurement in most European tunnels with load and moments also being derived in addition to surface pressure data. Klein et al [3] and Ruyten and Bell show excellent comparison of force and moment data derived from PSP against conventional balance data.

b. Particle Image Velocimetry

The Particle Image Velocimetry (PIV) technique is based on the ability to record and accurately track seeding particles in order to obtain the velocity field of the flow. While PIV is sufficiently mature, having been around for several decades, application of PIV in any tunnel poses several challenges, mainly seeding and illumination. The technique however, enables one to obtain the entire off-body flow field – both two as well as three-component velocity fields, which in conjunction with other data can present a complete picture of the flow physics. While PIV applications in low speed tunnels are routine, the need to install seeders and optical access has been one of the main challenges for PIV implementation in high speed tunnels in India.

At NAL, both 2D and Stereo PIV are routinely

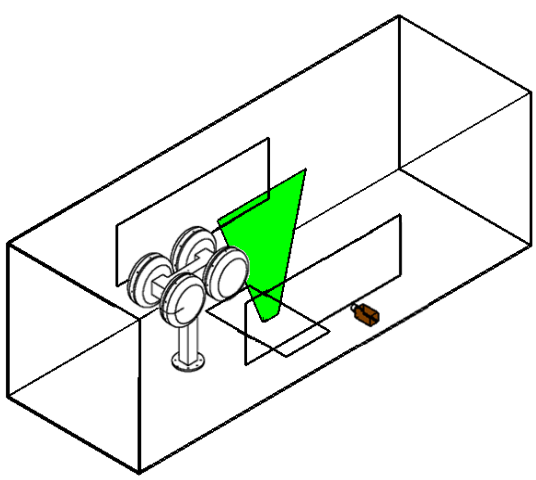

Fig. 2a. Schematic of imaging plane

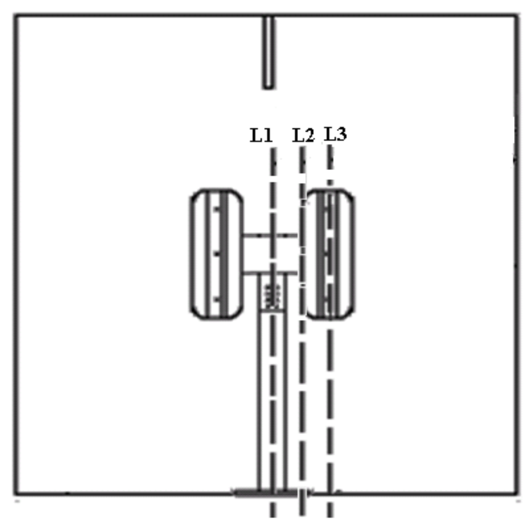

Fig. 2b. Location of the light sheets.

carried out in the 1.5m Low Speed Wind Tunnel. The flow-field with tracer particles is illuminated by a double pulsed, frequency doubled dual Nd:YAG, PIV

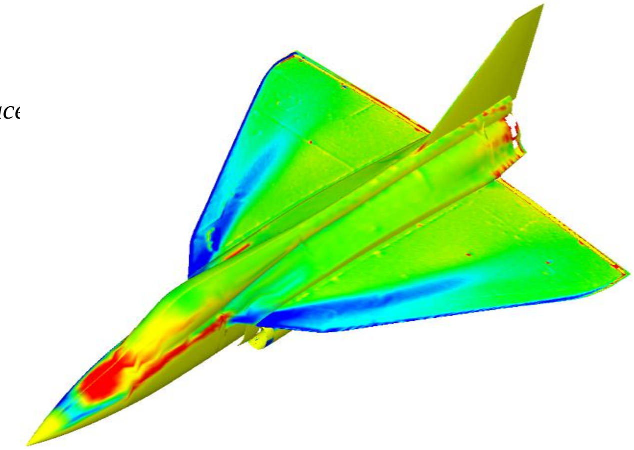

Fig. 1c Cp data from PSP mapped on to CFD

400 laser, providing with a nominal 400 mJ of energy per pulse at a 532-nm wavelength. The optimum performance of the laser is at 15 Hz (15 pairs per second). The beam from the laser is spread as a thin sheet of light with nearly flat intensity profile in the measurement plane using a few optical components to achieve a sheet thickness of 0.8 mm. A typical example of PIV application was the 2D and Stereo PIV study on a four-wheel landing gear at a freestream speed of 40m/s corresponding to a Reynolds number of 1 x 10^6 based on wheel diameter.

2-D PIV measurements were carried out in the wake behind the landing gear model at two different locations, one along the model centerline and another along the wheel parallel to the flow direction. Figures 2a, 2b show the views of the setup and the location of the light sheets.

A MotionPro X3 camera from RedLake, was used for the present 2-D PIV study along with Nikkor 35 mm lens. The camera has a sensor resolution of 1280 x1024 pixel^2. The camera was mounted at a distance of 1m from laser sheet (about 0.25m from the tunnel window) providing sufficient resolution at all the planes considered in the study.

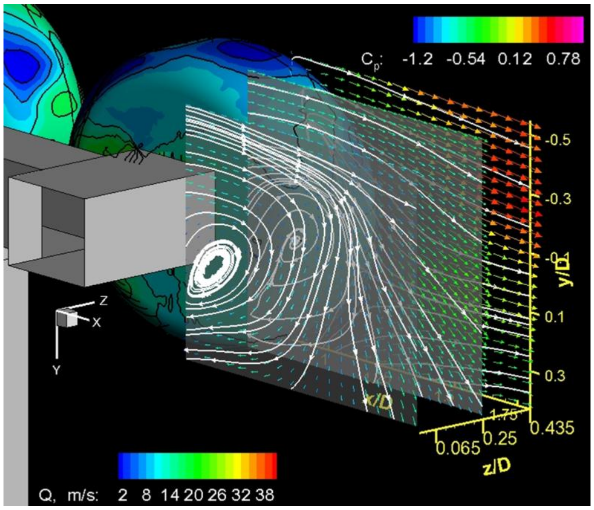

Fig. 2c. 2D PIV data at three stations

Figure 2c which presents 2D PIV data on three individual planes, shows the complexity of the flow and the understanding that can be obtained using PIV.

c. Background Oriented Schlieren

The Background Oriented Schlieren technique has the capability to obtain quantitative density data in a plane of interest for any flow with density gradients – 2D or 3-D [5]. The principle of the technique is the refractive index variation due to density gradients in the flow. The determination of the density field using BOS thus involves the following steps: (a) calculation of displacements in the background which is imaged through the flow of interest. This is done through a PIV-type cross-correlation algorithm. These displacements are the vectors of density gradient at each point; (b) calculation of the line-of- sight integrated density field by solution of the Poisson equation, which is the gradient of the above displacement; (c) use of optical tomography (filtered back-projection) to determine the density field in the actual plane of interest [6].

At NAL several advances towards the application of BOS in wind tunnels have been made in both the 0.3m trisonic wind tunnel as well as the Base flow facility.

Figure 3a shows the density field due the flow past a cone cylinder at zero incidence at M=2. The data show that the technique can capture density fields with good accuracy and can serve as a validation database for CFD in addition to providing insight in to the flow physics.

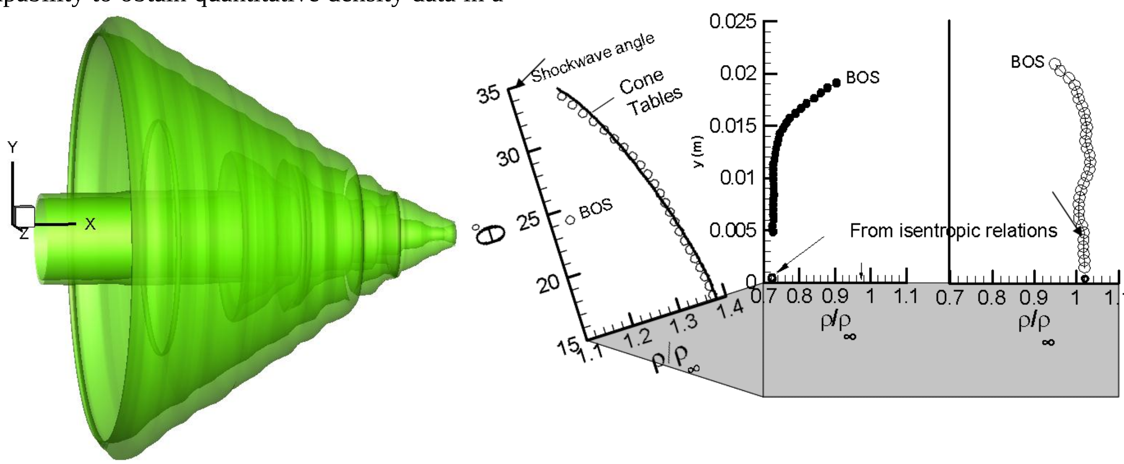

Fig. 3 (a) Iso-surface of density about a cone-cylinder at M=2 (b) Validation against cone tables.

3. Summary

Recently, many advances have been made in the development and application of non-intrusive flow diagnostics at NAL. Despite the fact that deployment of these techniques for routine usage in high speed tunnels poses several challenges, the understanding of flow physics which are obtainable from such techniques, make the effort worthwhile. Future wind tunnels should also be designed with such optical techniques in mind to enable maximum utilization of these advances.

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